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VISUAL ACUITY IN YELLOW HEADLIGHTS

by

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ABSTRACT

It has been claimed in France, in support of the use of yellow headlights, that visual acuity (the ability to see fine detail) in the light from filament lamps is increased by about 8% by passing the light through a selective yellow filter in spite of a 15% loss of total light. The claim has been tested at the Laboratory and a loss of about 2½% in visual acuity obtained.

When the light lost in the filter was made up by increasing the power of the lamp, visual acuity was found to be about 3% higher in the yellow light than in white light.

In the Laboratory's experiments the age of the observer did not appear to affect the result.

It is concluded that if white headlight bulbs (or lenses) were changed to yellow there would be very little change in visual acuity (between a loss of 1% and a gain of 1%) at equal electrical power, but a small gain in visual acuity (of about 3%) at equal luminous intensity.

Other effects of such colour changes have not been studied at the Laboratory (e.g., the effects on contrast sensitivity or susceptibility to glare).

1. INTRODUCTION

The use of yellow headlights was made obligatory in France in 1939. According to Devaux[1] the evidence leading to this step was in papers published by Monnier and Mouton,[2] the validity of which has been questioned by Richards[3] and others. Devaux, however, claimed that the results of the pre-war researches had been confirmed by those of a post-war laboratory investigation carried out by Pagès and Fleury,[4] who found that when a selective yellow filter was introduced between the eyes of their subjects and a white light display there was:

(i) an improvement of 8 per cent in visual acuity* in spite of the loss of light in the yellow filter (though not when a glare source was introduced),

* Visual acuity is a measure of the ability of the eye to discern fine detail.

(ii) a reduction of 26 per cent in the time to adapt to a glare source, and

(iii) a reduction of 24 per cent in the readaptation time after the removal of the glare source.

A review of the account of this latter experiment revealed a number of apparently unsatisfactor features which could possibly have led to an erroneous result. It was noted, for example, that each observer made only one set of observations with light of each colour and always in the same order–in white light first and in yellow light afterwards. It is possible therefore that the better performance of the subjects in the second session was due to practice and not to the change in the colour of the light.

To provide a check on the findings relating to visual acuity two experiments have been carried out at the Laboratory, under two slightly different sets of conditions, as explained in 2 below. The results obtained are discussed together with those of some new French experiments, reported since the Laboratory's experiments were carried out.

2. THE BASIS OF COMPARISON

The spectral transmission curve shown as (a) in Fig. 1 was used by Devaux[1] to indicate what is meant by a selective yellow filter. The alleged beneficial effect of such a filter is attributed to the almost complete removal of blue light with a wavelength less than 480 mμ and a diminution of blue–green light in the wavelength band 480–510 mμ. It will be noted that useful light of longer wavelengths (green, yellow and red) is also lost, partly because of non-selective reflections at the surfaces of the filter. The action of the filter on light from C.I.E. standard illuminant A (i.e. light of colour temperature 2854°K, approximating to that of white headlights) is shown in Fig. 2. The areas shaded represent the amounts of blue and blue–green light removed whilst the remainder of the area between the two curves represents the unwanted loss of useful light. The overall transmission is 83 per cent and about half of the light lost is accounted for by reflections at the filter. The filters used in the Laboratory's experiments were chosen to be similar to that described by Devaux - see Fig. 1 and 3.4.

If the assumption is made that the transmission of the filter used by Pagès and Fleury was 85% and that half of the total loss of light was due to surface reflections, it is possible to obtain an estimate of the relative visual acuities in yellow and white light, at equal luminance levels, by using the data of Shlaer[7] for the variation of acuity with luminance when no change in spectra composition is involved. Proceeding in this way it is found that if Pagès and Fleury's results were correct the visual acuity for yellow light must be 16 per cent higher than for white light at equal luminance levels.

Clearly, changing one of the existing clear glass components of a headlight for a similar selective yellow component is a more efficient way of changing from white to yellow headlights than inserting a separate selective yellow glass filter since the additional surface reflections can be avoided. This is what is done in France : yellow glass is used instead of clear glass for either the lamp bulb or the headlight lens. Such headlights give about 92.5 per cent of the intensity of equivalent white headlights. Making use of Shlaer's data, as before, it is found that if visual acuity in yellow light were really 16 per cent higher than in white light at equal luminance levels, then the change from clear to yellow glass would be expected to result in a gain of about 12 per cent in acuity. The greater efficiency of the yellow light (so far as acuity is concerned) would be expected (on these assumptions) to much more than offset the loss of light.

Experiment A was essentially a repeat of Pagès and Fleury's experiment, i.e. the determination of the effect on visual acuity of introducing a selective yellow filter without any compensation for the losses in light which the filter causes. Experiment B was an attempt to determine the effect on visual acuity of a change from white to yellow light, whilst keeping the luminance level constant. From the results obtained a new estimate is derived of the effect on acuity which would be obtained if the light from headlights was changed from white to yellow headlights by means of a change from clear to yellow lamp-bulbs (or headlight lenses). Such a change is not easily studied by direct experiment.

3. THE DISPLAY

3.1 The general arrangement

In both experiments the display consisted essentially of a photographic transparency bearing an array of black Landolt split rings illuminated from behind, though the detailed arrangements were slightly different in the two experiments. In experiment B (but not in experiment A) there was an additional adaptive field surrounding the test field formed by the transparency. The sizes and luminances of the test field and surround are discussed in 3.3.

3.2 The transparencies

There were four transparencies each bearing twelve Landolt rings arranged in two rows in order of decreasing size. The aim was to have each ring 5% less in size than the one preceeding it, the largest having a gap of 3.71 mm (0.146 in) and the smallest a gap of 2.11 mm (0.083 in). In fact the sizes of the rings departed by as much as ± 2.5% from the nominal values. Since these departures from the required sizes were appreciable compared with the differences between successive rings the experiment had to be designed to eliminate their effect on the results.

3.3 The illuminating systems

3.3.1 The illuminating system used in experiment A. This system utilised a box with two compartments both painted white internally. The smaller of the two compartments contained a 6W 12V car sidelight lamp and had a small aperture enabling reflected light to enter the larger compartment. This compartment had an open end over which could be mounted a frame carrying the transparency (together with a yellow filter when observations were being made in yellow light). The transparency was therefore seen against a background formed by the interior walls of the larger compartmen of the box.

Although the white paint used on the interior of the box was of the type recommended for use on photometric integrating spheres(5), and designed to be as neutral as possible, there was appreciable selective absorption of blue light relative to red because of the multiple reflections involved.

The lamp was therefore overrun (17v) so that the colour temperature of the light emerging from the box was about 2850°K, a value which is between those obtained from dipped (2820°K) and full (2890°K) British headlights with clear bulbs.

The mean luminance of the clear parts of the transparency without the yellow filter was 0.15 cd/m^2 (0.045 ft.L), about 6 per cent above this value at the beginning of the experiment and 6 per cent below it at the end. At any one time the variation in luminance over the clear parts of the transparency was less than ± 5 per cent.

3.3.2 The illuminating system used in experiment B. This also consisted of a box with two compartments, both painted white internally with integrating sphere paint. (Fig. 3). The smaller of the two compartments, contained a 60W 12V clear headlamp bulb and had a slot to permit the introduction of a filter between this lamp and an aperture into the larger compartment. A four feet square sheet of opal perspex formed the side of the large compartment opposite the aperture from the smaller compartment. A frame, to carry the transparency, was fixed onto the centre of the outside face of the screen. In order to spread the light as evenly as possible over the perspex screen an opaque hollow white cone was mounted in the large compartment between the aperture and the screen (see Fig. 3 and Plate 2).

As in the first experiment the lamp was overrun (14V) so that the colour temperature of light emerging from the box was about 2850°K.

The mean luminance of the clear parts of the transparencies was 0.12 cd/m^2 (0.035 ft.L) and that of the surrounding screen 0.17 cd/m^2 (0.049 ft.L). The variation in these mean luminances during the experiment was ± 5 per cent. At any one time the variation in luminance over the clear parts of the transparency was ± 1 per cent and over the surrounding screen about ± 10 per cent.

3.4 Filters

Because the illuminating systems were different in the two experiments filters of different sizes were required. They also differed slightly in their spectral transmission characteristics.

3.4.1 The filters used in experiment A. It was convenient (see Fig. 3) to have four frames to mount over the open end of the illuminating box and to have a pair of yellow filters to add to two of the frames. The spectral transmission curves of the two filters were almost identical – one is compared in Fig. 1 with the curve given by Devaux[1] to illustrate the selective yellow glass used for French headlamp bulbs. It is assumed that the filter used by Pagès and Fleury was also similar to that described by Devaux but they give no information on this point. The overall transmission of the filter used in Experiment A was 85 per cent compared with 83 per cent for that given by Devaux.

3.4.2 The filters used in experiment B. A smaller yellow filter was required to fit the slot in the illuminating system of experiment B. Its spectral distribution curve, also shown in Fig. 1, differed slightly from the filters used in experiment A. The overall transmission of this filter was 83 per cent.

For observations with white light a neutral filter was produced from ground glass so that the luminance of the perspex screen in white and yellow light were the same.

3.5 Comparison of the arrangements with the French experiment

There were several differences between the experimental arrangement employed by Pagès and Fleury and those employed in the present experiments.

(i) The viewing distance was 8.3 m (27.9 ft) in the French experiment as against 4.6 m (15 ft) in the Laboratory's experiments.

(ii) There was an adaptive field round the test field in the French experiment but only in the second of the Laboratory's experiments.

(iii) The luminance of the test field in the French experiment (0.1 cd/m^2) was approximately equal to that in the Laboratory's second experiment and a little lower than that in the Laboratory's first experiment.

(iv) The filter was placed in front of the subject's eyes in the French experiment instead of between the light source and the test field in the Laboratory's experiments.

None of these differences appears likely to have introduced a bias in favour of either white or yellow light.

4. EXPERIMENTAL DESIGN

In each experimental session two transparencies were used with yellow filters and two without so that half of the observations were made in yellow light and half in white. The subject was shown all four transparencies in all four positions, with observations in yellow light alternating with those in white light. This was necessary to obviate effects due to learning, fatigue, etc. in the subjects and to a slow fall in the light output of the lamp. Each time the subject was asked to indicate the position of the gap in each ring in the array. A different random order of presentation of the arrays was used for each subject, half of the subjects starting with an observation in yellow light and the other half in white light.

In order to eliminate the effect of the small differences noted in the sizes of rings on the different transparencies each observer took part in two experimental sessions, the two transparencies which were shown in white light in the first session being shown in yellow light in the second session. Since there were in effect 16 different orders of ring position it was considered very unlikely that the subject's performance in the second session could be aided by his memory of what he had been shown in the first session. Usually the sessions were on different days.

5. EXPERIMENTAL PROCEDURE

Each subject entered the darkened laboratory used in the experiment 15 minutes before he commen ced making observations. He then sat down behind a wooden screen containing a slot large enou for him to have a clear view of the display through it with both eyes. Round the slot was a head-rest. These arrangements were made to ensure that the observer's eyes were always at the correc level and at a constant distance from the display.

The subject was then given a trial run both to familiarise him with the procedure and to enab the experimenter to estimate the distance at which he was likely to be able to achieve about 50 pe cent success in estimating the positions of the gaps in the rings. The wooden screen was then se at that position for both the experimental sessions with that observer. The distances varied from about 3.5 m (11.5 ft) to 7.9 m (26.0 ft) (see Tables 1A and 1B).

The subjects were instructed to try to read each ring starting with the largest and working progressively towards the smallest. Thus each subject was asked to determine the position of the gap in 384 split rings. The largest rings were clearly visible and the smallest rings impossible to read but in between these extremes there was a range of rings which could be read with a probability which varied according to their size.

It is of importance to record that the subjects were not told that they were taking part in a comparison of white and yellow light: they were told only that their vision was being tested. At the low luminance used the difference in colour between the white and yellow displays (never seen together) was not obvious. In the first experiment the great majority of observers did not notice th colour change. However, in the second, with a much larger illuminated surround, most observers became aware of the colour change, but, none guessed the real purpose of the experiment.

6. THE SUBJECTS

The 32 subjects in Experiment A and 20 subjects in experiment B were all members of the staff of the laboratory. Their ages ranged from 16 to 67 years.

Thos who normally wear spectables for middle distance work did so in the experiment (12 in A and 10 in B – see tables 1A and 1B). Of the other subjects, those who normally wear spectacle for reading only, made their observations without spectacles (5 in experiment A and two in experiment B). The subjects Snellen ratings as obtained on a standard optician's chart are given in Tables 1A and 1B.

All subjects had normal colour vision according to their performance in the Ishihara test.(6)

7. RESULTS

The detailed scores for each subject and for each colour of light are given in Appendices 1A and 1B. The main interest however lies in the differences between the scores for the two colours of light which are given in Tables 1A and 1B of the main text.

TABLE IA

Summary of results and details concerning the subjects in Experiment A

Subject No.	Age	Whether spectacles worn	Acuity	Observation distance M (ft)	Score for white light minus score for yellow light for each ring number ⺊												Subject total ⓧ
					1	2	3	4	5	6	7	8	9	10	11	12	
1	18	No	6:6	3.8 (12.4)	−1	2	0	2	6	6	−3	0	3	0	−3	4	+ 16
2	20	Yes	6:4.5	6.9 (22.6)	−4	2	1	2	0	−2	4	5	2	1	1	−2	+ 10
3	21	No	6:4.5	6.9 (22.7)	0	−1	0	−3	4	1	4	1	−1	0	0	−2	+ 3
4	21	No	6:4.5	5.5 (18.0)	0	0	0	0	2	−1	3	3	1	−3	−1	−4	0
5	21	No	6:4.5	5.9 (19.5)	0	0	−1	0	0	−1	−3	0	1	−1	0	0	− 5
6	22	No	6:12	3.8 (12.3)	−2	0	−1	−2	4	−1	0	0	0	0	0	0	− 2
7	24	No	6:4.5	5.9 (19.3)	0	0	−2	−2	1	2	4	1	0	−1	0	0	+ 3
8	26	No	6:4.5	6.9 (22.6)	2	0	0	0	5	3	0	−4	−3	0	1	0	+ 4
9	27	No	–	5.3 (17.3)	0	1	1	−1	4	2	0	4	3	1	0	0	+ 15
10	28	* No	6:4.5	7.9 (25.8)	0	−1	−2	2	0	1	5	−3	0	1	−3	−4	− 4
11	28	No	6:4.5	7.9 (26.0)	−1	1	2	3	−2	8	4	2	6	0	3	2	+ 28
12	28	Yes	6:4.5	6.8 (22.4)	1	0	5	3	0	2	−2	−3	1	−1	6	3	+ 15
13	29	No	–	4.8 (15.7)	−1	2	−4	3	0	1	0	−3	0	0	0	0	− 2
14	31	Yes	6:4.5	4.3 (14.1)	0	0	1	0	0	1	−2	3	5	−1	4	2	+ 13
15	33	Yes	6:4.5	3.9 (12.7)	4	−1	−1	0	2	0	3	−1	2	0	1	2	+ 11
16	36	Yes	6:4.5	4.5 (14.8)	1	0	2	−1	1	2	0	−3	0	−2	0	4	+ 4
17	37	No	6:4.5	7.3 (24)	−2	−1	−2	−2	4	2	1	1	−1	0	0	0	0
18	38	No	6:4.5	7.2 (23.7)	0	0	0	−1	3	1	−2	−1	−1	1	−1	0	− 1
19	39	Yes	6:4.5	6.8 (22.4)	0	0	1	2	−4	4	2	2	−2	−1	2	1	+ 7
20	39	Yes	6: 4.5	6.1 (19.9)	0	5	−1	2	−3	3	3	3	−1	0	0	0	+ 11
21	40	No	6:4.5	6.0 (19.6)	0	0	0	1	1	3	−1	0	−2	−2	−1	0	− 1
22	47	No	6: 4.5	6.6 (21.5)	3	−1	0	0	−2	−3	−1	3	1	0	1	0	+ 1
23	48	Yes	6:4.5	4.5 (14.8)	−1	1	−2	−1	4	0	−2	0	1	0	0	0	0
24	52	*No	6: 4.5	4.1 (13.3)	0	−2	−1	1	0	−1	−1	2	2	1	−1	3	+ 3
25	53	*No	6: 4.5	4.5 (14.8)	0	−2	0	1	0	3	−2	3	4	3	2	1	+ 13
26	54	Yes	6:6	4.5 (14.8)	0	−1	−1	0	−1	0	2	3	−2	0	−1	−2	− 3
27	56	Yes	–	5.1 (16.7)	2	2	−2	0	6	7	4	0	0	0	0	0	+ 19
28	61	Yes	6:4.5	4.1 (13.5)	−2	−1	0	2	−2	−2	−1	−2	−2	−1	−1	0	− 12
29	62	*No	6:6	4.2 (13.9)	0	0	1	1	−1	1	0	−1	0	0	0	0	+ 1
30	63	Yes	6:4.5	4.2 (13.6)	−1	3	2	−2	−1	2	2	1	0	0	0	0	+ 6
31	63	*No	6:4.5	6.6 (21.5)	0	2	2	2	5	−1	3	4	3	−1	1	1	+ 21
42	66	No	6:6	5.3 (17.3)	−4	6	0	1	−2	4	1	−2	−2	3	−1	−1	+ 3
Ring totals					−6	16	−2	13	34	47	25	18	18	−3	9	8	+ 177

* Normally wear spectacles for reading but not for middle-distance seeing

ⓧ + ve scores are in favour of white light

− ve .. .. yellow ..

⺊ Ring No. 1 was largest and Ring No. 12 smallest

TABLE IB

Summary of results and details concerning the subjects in Experiment B

Subject No.	Age	Whether spectacles worn	Acuity	Observation distance M (ft)	Score per white light minus score per yellow light for each ring number ⊀ 1	2	3	4	5	6	7	8	9	10	11	12	Subject total
1	16	No	6:4.5	5.5 (17.9)	0	0	0	0	0	−1	−6	0	0	0	0	0	−7
2	20	No	6:4.5	6.7 (22.0)	0	0	0	0	−1	−4	+2	+3	−3	−1	0	0	−4
3	21	No	6:4.5	5.7 (18.7)	0	−4	0	+2	−5	−1	−4	−3	−1	−1	−1	0	−18
4	21	Yes	6:4.5	5.8 (19.0)	+1	+1	−4	−2	−2	+1	−7	−3	−3	−2	0	0	−20
5	22	Yes	6:4.5	5.9(19.5)	0	0	−1	−2	0	−8	+1	−4	−3	0	−1	0	−18
6	22	No	6:4.5	6.1 (20.1)	0	−1	+2	+3	−2	0	+3	−1	0	−1	−1	−1	+1
7	23	No	6:4.5	5.8 (19.0)	0	+1	−1	+2	0	−3	+1	+2	−3	0	−1	−1	−3
8	25	Yes	6: 4.5	6.2 (20.2)	0	0	+1	−1	−2	0	−1	+4	+1	−1	−3	−3	−5
9	27	No	6:4.5	4.0 (13.0)	0	0	+1	−1	−2	−4	−3	−2	0	0	0	0	−11
10	30	No	6:4.5	6.1 (19.9)	0	0	0	0	−2	−1	−1	−2	−3	−2	0	−1	−12
11	33	Yes	6:4.5	5.2 (17.0)	0	−2	−1	0	−3	−2	−2	−1	−3	−1	−1	0	−16
12	37	Yes	6:4.5	5.0 (16.5)	0	0	+2	−2	−3	−2	−1	0	−3	0	0	0	−9
13	40	Yes	6:4.5	5.2 (16.9)	0	−2	0	0	+1	+2	−2	−4	0	0	0	0	−5
14	47	Yes	6:4.5	5.3 (17.5)	0	0	0	0	0	−1	−2	+2	−1	0	0	0	−2
15	47	No*	6:4.5	5.5 (17.9)	+1	−1	−1	−2	−5	−3	−1	−1	−2	0	0	0	−15
16	50	Yes	6:4.5	4.2 (13.9)	0	−6	0	−1	0	−6	+2	−4	+1	+1	+1	0	−12
17	53	No*	6:4.5	5.8 (19.1)	+1	−1	+2	−2	+4	+4	0	−1	0	−2	0	0	+5
18	54	Yes	6:4.5	5.0 (16.5)	0	0	0	0	0	−1	−1	+1	−5	−5	−2	−2	−15
19	63	No	6:4.5	4.2 (13.6)	0	+1	−3	0	+1	−2	−5	−5	0	0	0	0	−13
20	64	Yes	6:4.5	3.5 (11.5)	0	0	−2	−2	−1	−1	−3	−3	0	0	0	0	−12
Ring totals					+3	−14	−5	−8	−22	−33	−30	−22	−28	−15	−9	−8	−191

* Normally wear spectacles for reading but not for middle-distance seeing

In Table 1A it will be noted that the majority of subject totals for these difference scores are positive, the mean total for all subjects together is significantly greater than zero at the 99 per cent level of confidence. Thus in this test (in which there was no compensation for the loss of light in the yellow filter) there was a loss in visual acuity due to the change from white light to yellow filtered light.

In the second experiment in which the loss of light in the filter was made up by increasing the light output of the lamp the corresponding totals are negative (see Table 1B) and there was therefore a gain in visual acuity due to the change from white to yellow filtered light (significant at the 99 per cent level of confidence).

Another way of presenting the results and one which yields a quantitative estimate of the effect of the yellow filter on acuity, is to plot the percentage of correct responses against the size of the gap in the ring for the plain and filtered light as in Figs 4A and 4B and to draw smooth curves through the points. Figures 4A and 4B were produced by plotting the mean number of the correct responses out of 16 against the ring number but scales of percentage correct and of gap size have been added. Plotting against ring number is equivalent to plotting against the logarithm of gap size.

The curves are sigmoid as is normal for such data. For large rings the proportion correct approaches 100 per cent, but does not reach it because some inexplicable errors were made. For small rings the proportion correct approaches zero but does not reach it because a few subjects continued to guess when they could no longer identify the rings and had, of course, a 1 in 4 probability of being right by chance (no correction was made for these because other observers did not attempt to guess). Probably it is for these reasons that the white and yellow curves tend to merge for large and small rings.

For rings Nos 4–9 in Fig 4A and rings Nos 5–9 in Fig 4B the curves appear to be straight and parallel but displaced from one another by approximately one half ring in Fig 4A and five-eighths of a ring in Fig 4B. For equal performance in experiment A (strictly over the range of 30 to 80 per cent success) the rings would have to be about 2½ per cent larger when the light is yellow filtered than when it is white. This means that visual acuity was about 2½ per cent higher in the white light than in the yellow filtered light in Experiment A. In experiment B the visual acuity was found to be about 3 per cent higher in the filtered light than in the plain light. The difference between the results obtained in experiments A and B is accounted for by the difference between the conditions in these experiments: this point is taken up again in 8.

Since there is a progressive yellowing of the lens of the eye with age, the results have been examined to see whether the effect was different for old observers than for young observers. In Figs 5A and 5B, the differences between the scores for white and yellow light have been plotted against age. No correlation with age can be detected in either set of results.

8. DISCUSSION

There are three cases of interest to consider:

Case A – The addition of a selective yellow filter to an existing white headlight. (as when a British motorist fixes pieces of yellow material in front of his headlights before going to France).

Case B – The modification of a white headlight design to produce a yellow headlight of equal intensity (For example by colouring the glass of the lens or bulb and increasing the power of the lamp to make up for the light filtered out).

Case C – Colouring the glass of the lens or bulb yellow whilst keeping the power of the lamp constant. (This case differs from case A in that unnecessary losses of light due to additional surface reflections are avoided but losses necessary to produce yellow light from white light remain).

Pagès and Fleury studied only case A. However, estimates of the results that they would have obtained, had they studied cases B and C, can be made from their result on the assumptions that

(i) the filter introduces a total light loss of 15 per cent;

(ii) half of this loss is due to surfaces reflections, and

(iii) the effect on acuity of changes in luminance without changes in spectral composition can be estimated from the data of Shlaer.(7)

The result of Pagès and Fleury for case A and the estimates for cases B and C obtained as above appear in Table 2.

The Laboratory's investigation covered both case A (in experiment A) and case B (in experiment B). From these results estimates of the result which would have been expected in case C can be made by making various assumptions. The simplest assumptions to make are that half of the total light loss resulting from the filter used in experiment A is due to unwanted surface reflections and that therefore, the results for case C would be the arithmetic mean of the results for cases A and B. These assumptions are only approximately true but are of the same order of accuracy as the experimental results being discussed. The results of the Laboratory's experiments A and B and the estimated result for case C, obtained as described above, appear in Table 2.

TABLE 2

Changes in acuity in changing from white to yellow headlights

	Pagès and Fleury	R.R.L.	
		Mean	95% probability range
Case A	+8%	-2.7%	-3.9% to -1.5%
Case B	+16%*	+3.0%	+1.7% to +4.4%
Case C	+12%*	+0.2% †	-0.8% to +1.1% †

* Estimated from the results for case A using assumptions explained in the text.
† Estimated from the results for cases A and B using assumptions explained in the text.

The only case covered both by the Laboratory and by Pagès and Fleury is case A and there is a big discrepancy between the results obtained – a loss of about 2½% by the former and a gain of 8 per cent by the latter. The results obtained by the Laboratory for case B agrees within the limits of experimental error with that obtained for case A, when allowance is made for the physical differences between the two cases by the method used in making the corresponding conversion of Pagès and Fleury's result. It seems very likely therefore, that Pagès and Fleury's result is in error and that the reason is the fundamental error of experimental design discussed in the introduction. Some support for this view is to be found in an account of a new experiment carried out by Pagès in collaboration with Lacoste.[8] In this the subjects were placed in a form of driving simulator and had to respond to light signals whilst carrying out a subsidiary task analagous to steering. No difference was found between their performance using white and yellow headlights in the absence of opposing headlights. (The results obtained with opposing glare are discussed below).

The Laboratory's results agree with that of Pagès and Fleury that when comparing headlights of equal intensity (case B) higher visual acuity is obtained with yellow headlights than with white headlights but disagree seriously about the magnitude of the effect. The results from the Laboratory's experiment B indicates that the visual acuity of drivers with normal eyesight is higher in yellow headlights than in white headlights of equal intensity by about +3 per cent (the 95 per cent probability interval is +2 per cent to +4 per cent).

It must be pointed out that visual acuity is only one possible measure of performance and not necessarily the most important: Pagès and Fleury also investigated other criteria which may be of greater importance, for example the time to adapt to a flare source and the time to readapt after the removal of the glare source, and concluded that these were reduced by using yellow light instead of white light. Unfortunately, the same fundamental error in experimental design was involved and these results too must be considered to be in doubt. However, some evidence in support of the view that disability glare may be less with yellow headlights than with white headlights of equal intensity was obtained by Pagès and Lacoste in one of the new experiments (referred to above) in which there were opposing dipped headlights.

9. CONCLUSIONS

The results of the two experiments carried out at the Laboratory are in substantial agreement.

They indicate:-

(i) that visual acuity for black objects seen against a bright background is marginally higher (about 3 per cent) if the background is illuminated by yellow-filtered tungsten light than if it is illuminated by plain tungsten light, provided that the luminance is the same in the two cases (i.e. provided the loss of light due to the filtering process is made up by increasing the power of the lamp).

(ii) that, when a comparison is made between headlights consuming equal electrical power, one of which has a yellow bulb (or lens) and the other a clear one, the difference in visual acuity is very small, somewhere between a loss of 1 per cent and a gain of 1 per cent

and (iii) that the relative effectiveness of white and yellow light with respect to acuity does not appear to be correlated with age.

It must be pointed out that other visual criteria have not been studied. For example, since there was no glare (in the experiments), any difference in the glare effects of white and yellow headlights was not investigated.

10. ACKNOWLEDGEMENTS

The authors are indebted to Mr. J.B. de Boer and Mr. J.J. Balder of N.V. Philips, Netherlands for helpful discussions on this problem and to the many members of the staff of the Laboratory who helped in the experiments, particularly to Mr. A.E. Walker, Mr. J.A. Reid and Mr. H. Austin for their valuable assistance with regard to the design of equipment and photometric measurements.

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APPENDIX IA

Scores for individual subjects and sizes of ring in the two colours of light in Experiment 1

Number of correct observations for each size of ring (out of 16)

White light

Subject number	Ring size number												Subject total
	1	2	3	4	5	6	7	8	9	10	11	12	
1	15	16	14	12	11	12	7	6	8	4	1	5	111
2	12	14	11	11	5	7	9	11	4	4	3	0	91
3	15	15	16	11	14	12	15	13	9	8	6	3	137
4	16	16	15	15	16	14	16	15	12	7	12	7	161
5	16	16	15	16	13	11	9	7	3	0	0	0	106
6	13	15	14	13	11	4	0	0	0	0	0	0	70
7	15	15	13	12	12	8	6	4	1	0	0	0	86
8	12	7	6	10	8	9	4	3	4	1	1	0	65
9	16	15	13	13	12	11	9	8	5	2	0	0	104
10	16	14	13	15	13	10	12	8	8	7	4	2	122
11	14	16	14	15	9	14	9	6	8	0	4	3	112
12	12	12	11	12	10	9	8	7	5	5	9	6	106
13	15	16	11	16	11	8	6	0	0	0	0	0	83
14	15	15	15	16	14	15	12	13	12	9	10	9	155
15	15	15	14	15	14	11	12	12	12	11	6	5	142
16	16	16	16	15	16	13	15	11	12	11	6	6	153
17	14	14	12	9	9	8	6	5	2	1	0	0	80
18	16	16	16	12	13	9	10	6	3	2	0	0	103
19	16	16	16	16	11	14	11	9	8	4	5	3	129
20	15	16	12	15	8	11	10	4	1	0	0	0	92
21	16	15	16	15	11	13	9	7	5	3	0	0	110
22	16	14	14	16	12	11	13	11	6	2	1	0	116
23	15	15	12	13	11	7	7	7	4	1	0	0	92
24	16	14	15	16	14	15	13	12	14	11	7	11	158
25	16	13	15	15	14	14	12	12	13	13	9	7	153
26	14	14	13	14	11	10	9	8	6	7	3	2	111
27	16	16	13	15	15	9	5	0	0	0	0	0	89
28	13	14	14	13	13	10	10	7	6	3	1	0	104
29	16	15	15	14	10	6	2	0	0	0	0	0	78
30	13	13	12	7	8	8	6	2	0	0	0	0	69
31	16	16	13	12	13	6	8	6	4	1	2	1	98
32	9	12	8	8	7	11	8	4	4	5	4	8	88
Ring total	470	466	421	427	369	330	288	224	179	122	94	78	3474

Number of correct observations for each size of ring (out of 16)

Yellow light

Subject number	Ring size number 1	2	3	4	5	6	7	8	9	10	11	12	Subject total
1	16	14	14	10	5	6	10	6	5	4	4	1	95
2	16	12	10	9	5	9	5	6	2	3	2	2	81
3	15	16	16	14	10	11	11	12	10	8	6	5	134
4	14	14	13	13	9	2	1	0	0	0	0	0	66
5	16	16	16	16	13	12	12	7	2	1	0	0	111
6	15	15	15	15	7	5	0	0	0	0	0	0	72
7	15	15	15	14	11	6	2	3	1	1	0	0	83
8	10	7	6	10	2	6	4	7	7	1	0	0	61
9	16	14	12	14	8	9	9	4	2	1	0	0	89
10	16	15	15	13	13	9	7	11	8	6	7	6	126
11	15	15	12	12	11	6	5	4	2	0	1	1	84
12	11	12	6	9	10	7	10	10	4	6	3	3	91
13	16	14	15	13	11	7	6	3	0	0	0	0	85
14	15	15	14	16	14	14	14	10	7	10	6	7	142
15	11	16	15	15	12	11	9	13	10	11	5	3	131
16	15	16	14	16	15	11	15	14	12	13	6	2	149
17	16	15	14	11	5	6	5	4	3	1	0	0	80
18	16	16	16	13	10	8	12	7	4	1	1	0	104
19	16	16	15	14	15	10	9	7	10	5	3	2	122
20	15	11	13	13	11	8	7	1	2	0	0	0	81
21	16	15	16	14	10	10	10	7	7	5	1	0	111
22	13	15	14	16	14	14	14	8	5	2	0	0	115
23	16	14	14	14	7	7	9	7	3	1	0	0	92
24	16	16	16	15	14	16	14	10	12	10	8	8	155
25	16	15	15	14	14	11	14	9	9	10	7	6	140
26	14	15	14	14	12	10	7	5	8	7	4	4	114
27	14	14	15	15	9	2	1	0	0	0	0	0	70
28	15	15	14	11	15	12	11	9	8	4	2	0	116
29	16	15	14	13	11	5	2	1	0	0	0	0	77
30	14	10	10	9	9	6	4	1	0	0	0	0	63
31	16	14	11	10	8	7	5	2	1	2	1	0	77
32	13	6	8	7	9	7	7	6	6	2	5	9	85
Ring total	474	448	427	412	330	270	251	194	150	115	72	59	3202

APPENDIX IB

Scores for individual subjects and sizes of ring in the two colours of light in Experiment B

Number of correct observations for each size of ring (out of 16)

White light

Subject number	Ring size number												Subject total
	1	2	3	4	5	6	7	8	9	10	11	12	
1	15	10	12	9	7	4	8	6	6	6	3	1	87
2	13	15	15	14	13	8	10	10	6	8	3	3	118
3	16	16	16	16	14	15	15	11	4	2	1	0	126
4	16	15	16	14	12	13	12	11	7	6	3	3	128
5	16	16	15	14	13	7	12	6	4	0	0	0	103
6	16	12	12	11	8	11	8	7	4	0	0	0	89
7	16	16	16	16	16	11	10	9	3	1	0	0	114
8	16	16	15	14	10	7	3	1	0	0	0	0	82
9	16	14	15	14	12	14	12	1	0	0	0	0	98
10	16	16	16	16	14	16	14	9	8	2	1	0	128
11	15	12	9	10	7	9	6	6	5	0	0	0	79
12	16	16	15	13	14	12	11	13	11	9	3	1	134
13	16	14	15	16	13	13	14	12	8	4	0	0	125
14	16	16	16	14	11	12	10	11	4	1	0	0	111
15	16	11	13	14	6	5	4	1	1	0	0	0	71
16	16	16	13	16	14	10	9	0	0	0	0	0	94
17	16	13	11	15	8	11	10	7	3	4	0	0	98
18	16	16	16	16	15	14	3	0	0	0	0	0	96
19	15	15	14	11	5	4	5	2	0	0	0	0	71
20	16	14	13	9	5	7	3	0	0	0	0	0	67
Ring total	314	289	283	272	217	203	179	123	74	43	14	8	2019

Number of correct observations for each side of ring (out of 16)

Yellow light

Subject number	Ring size number												Subject total
	1	2	3	4	5	6	7	8	9	10	11	12	
1	15	16	12	10	7	10	6	10	5	5	2	1	99
2	13	14	16	12	13	11	9	8	9	8	4	4	121
3	16	16	16	16	16	16	16	11	7	4	1	1	136
4	16	16	14	11	14	13	9	12	7	7	4	4	127
5	16	16	16	16	13	15	11	10	7	0	1	0	121
6	15	13	10	13	4	7	8	8	4	2	0	0	84
7	16	16	16	16	16	12	12	7	4	1	0	0	116
8	16	16	14	15	12	11	6	3	0	0	0	0	93
9	16	16	15	14	11	12	14	5	0	0	0	0	105
10	16	16	16	16	13	12	16	12	5	1	1	0	124
11	14	11	13	12	9	8	13	9	8	2	0	0	99
12	16	16	14	14	16	12	12	9	10	10	6	4	139
13	16	16	16	16	16	15	16	13	11	5	1	0	141
14	16	16	14	16	14	14	11	11	7	1	0	0	120
15	16	15	13	12	11	6	8	4	2	1	1	0	89
16	16	15	16	16	13	12	14	5	0	0	0	0	107
17	16	13	11	15	8	12	11	6	8	9	2	2	113
18	16	16	16	16	15	15	9	0	0	0	0	0	103
19	14	16	15	13	10	7	6	3	2	0	0	0	86
20	16	14	15	11	6	8	6	3	0	0	0	0	79
Ring total	311	303	288	280	237	228	213	151	96	56	23	16	2202

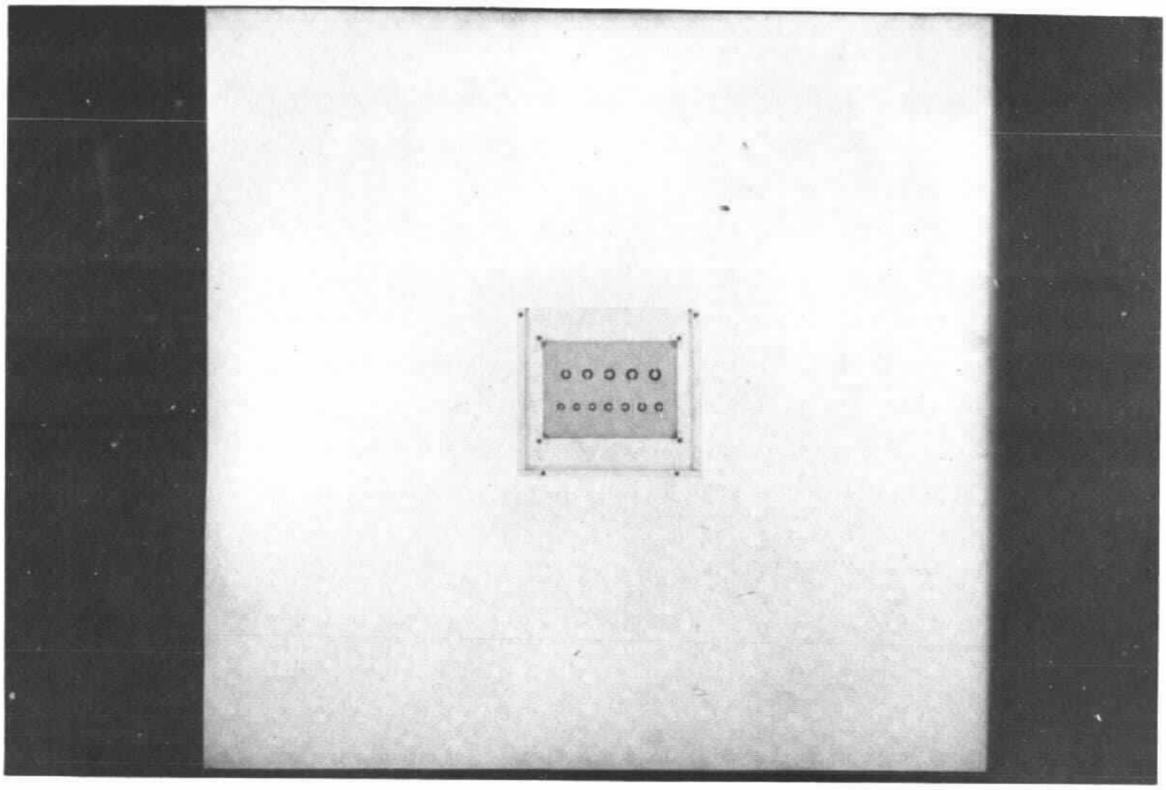


PLATE 1
The display as seen by the subject in experiment B.

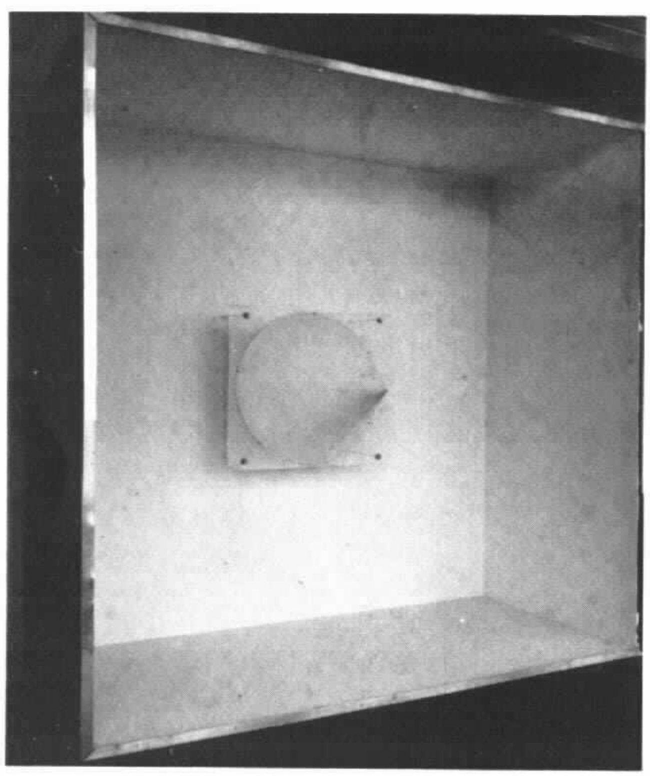
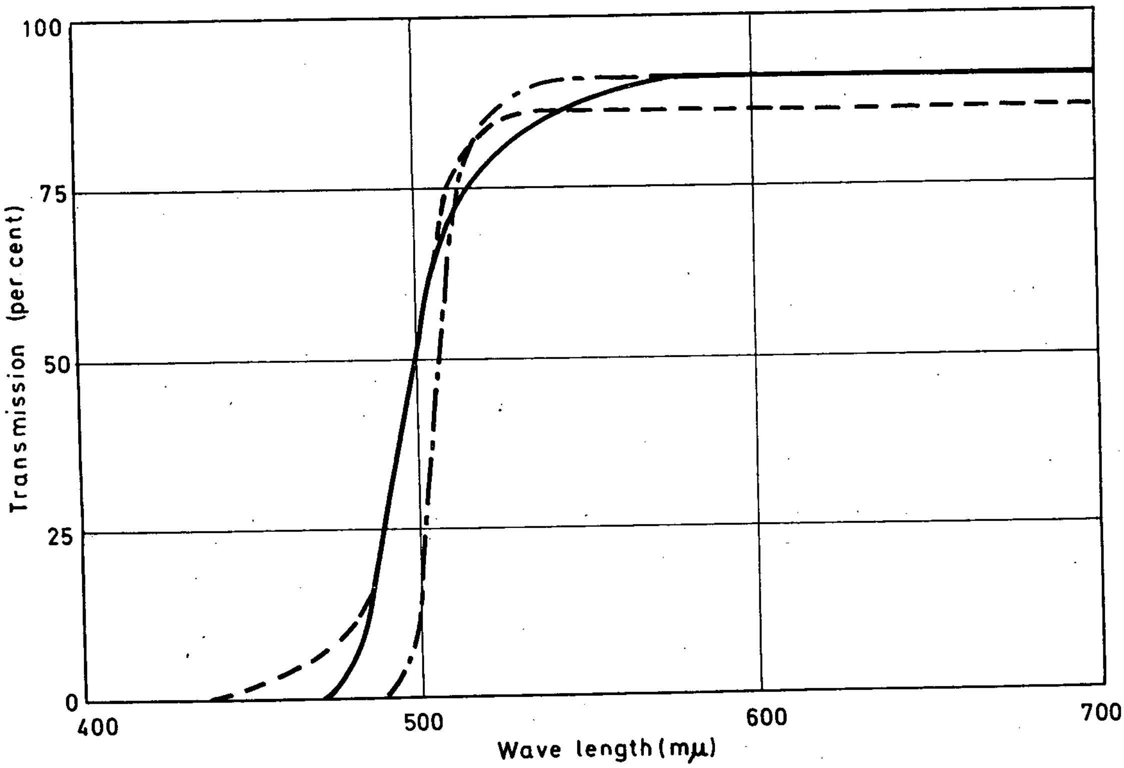


PLATE 2
The interior of the larger compartment of the illuminating system used in experiment B.



(i) — — — Selective yellow filter described by Devaux
(ii) ——— RRL yellow filter (experiment A)
(iii) —·— RRL yellow filter (experiment B)

Transmission for light of colour temperature 2854°K
(i) 83% (ii) 85% (iii) 83%

Fig.1. SPECTRAL TRANSMISSIONS OF YELLOW FILTERS USED IN FRANCE AND IN THE RRL EXPERIMENTS

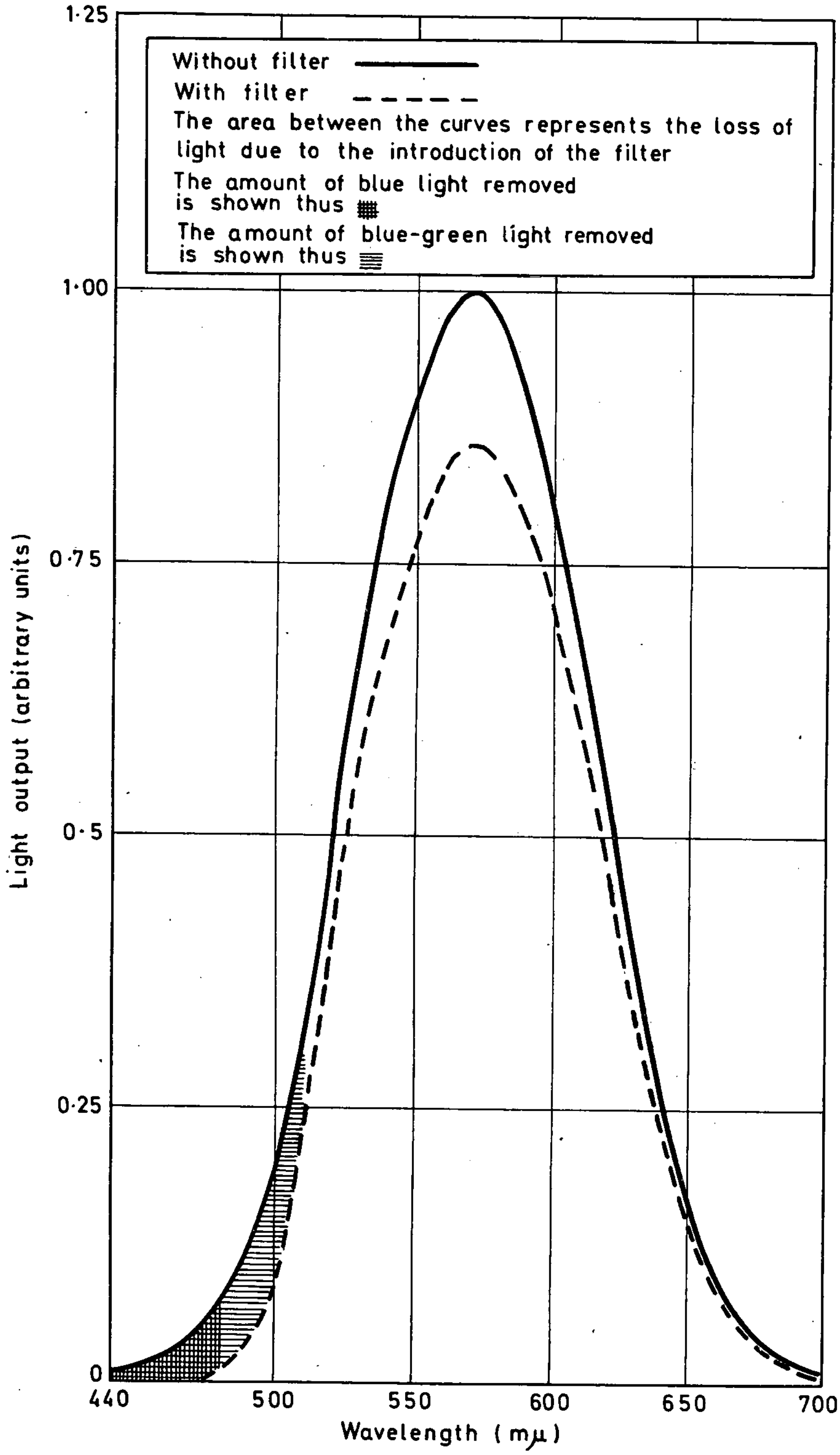


Fig.2. LIGHT OUTPUT AT DIFFERENT WAVE LENGTHS OF A SOURCE WITH A COLOUR TEMPERATURE OF 2854°K WITH AND WITHOUT A SELECTIVE YELLOW COLOUR FILTER AS DESCRIBED BY DEVAUX (1)

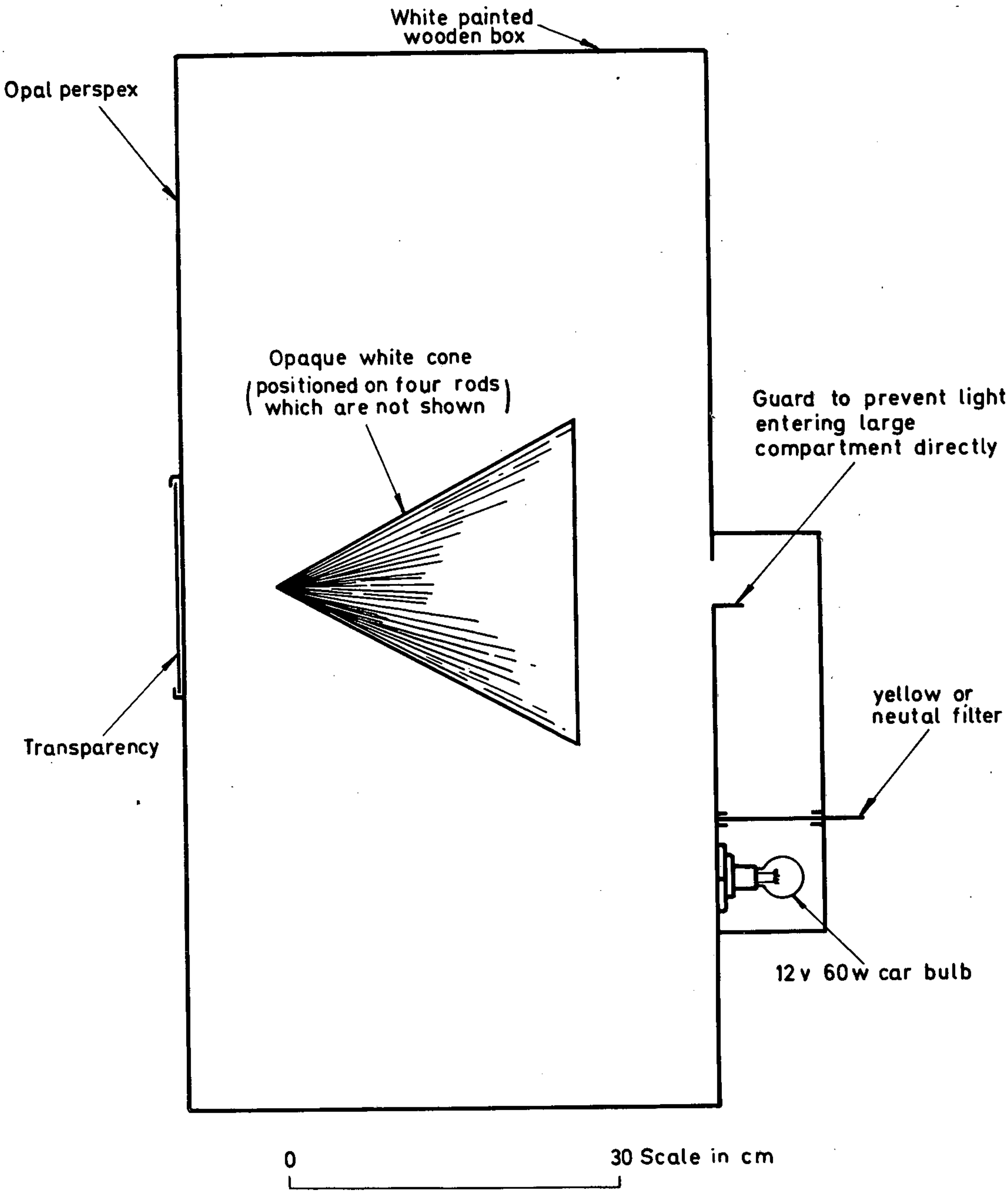


Fig. 3. SECTION THROUGH PLAN VIEW OF THE ILLUMINATING SYSTEM USED IN EXPERIMENT B

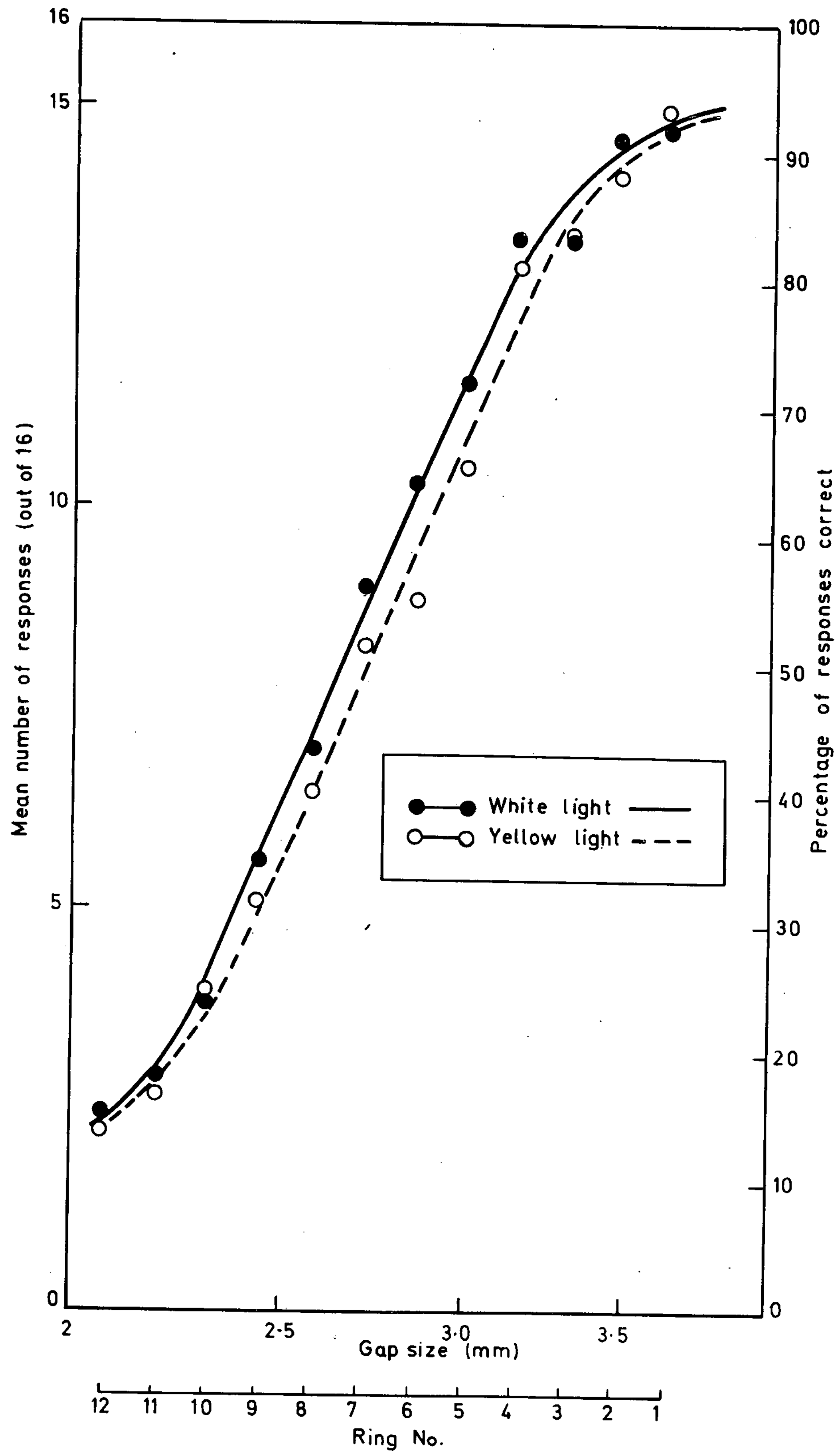


Fig. 4A. MEAN SCORES FOR THE GROUP OF 32 SUBJECTS (EXPERIMENT A)

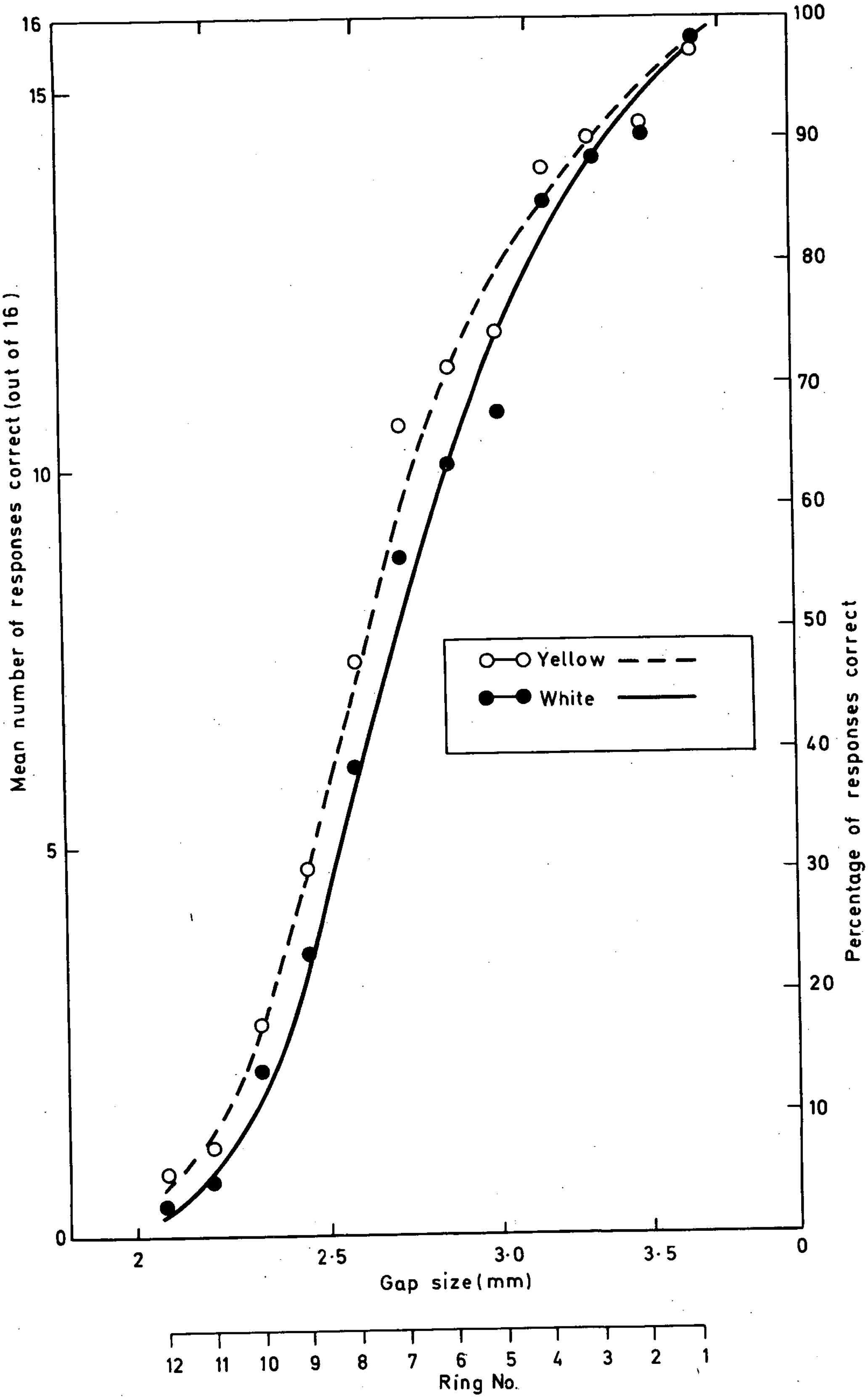


Fig. 4B. MEAN SCORES FOR THE GROUP OF 20 SUBJECTS (EXPERIMENT B)

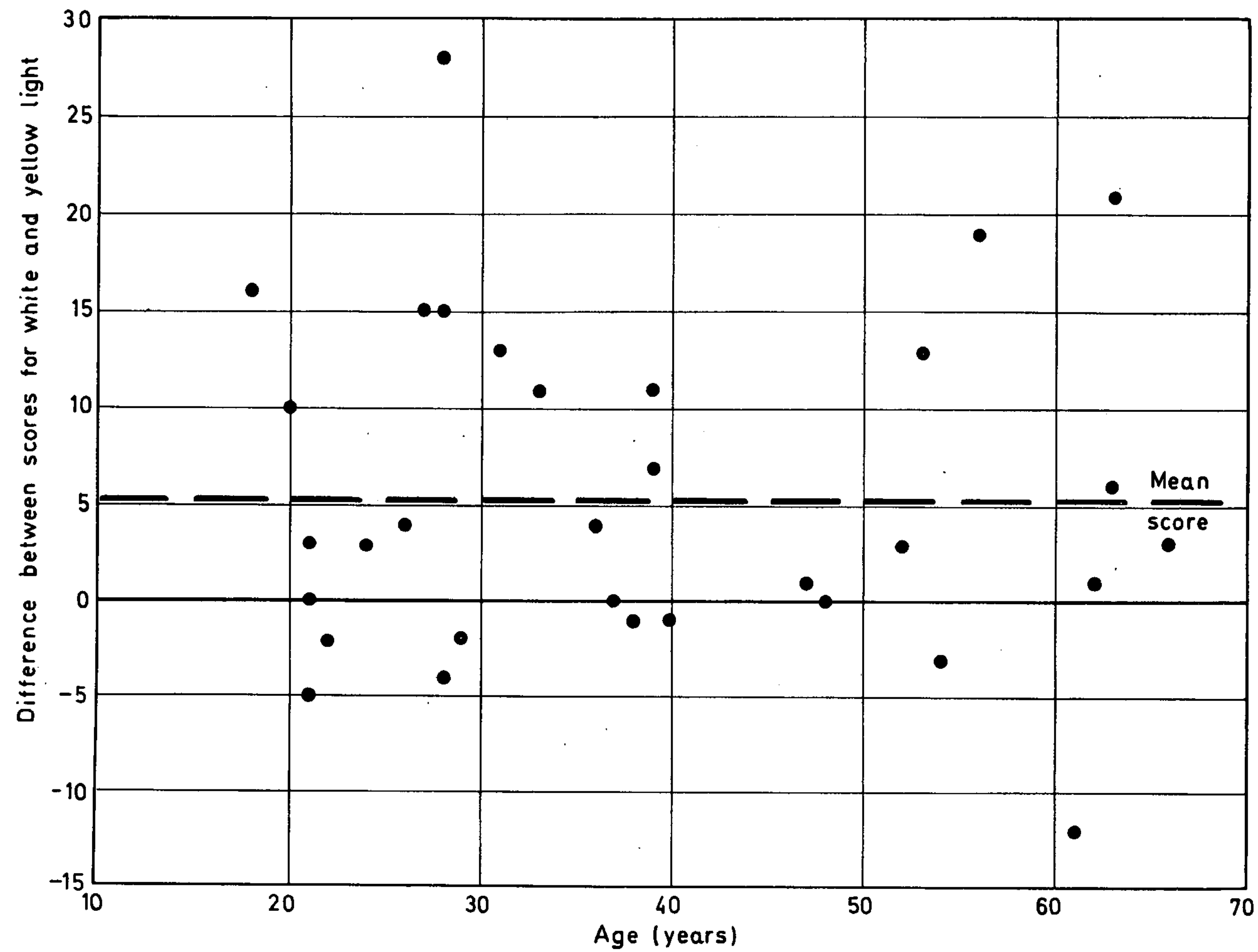


Fig. 5A DIFFERENCE BETWEEN TOTAL SCORES FOR WHITE AND YELLOW LIGHT PLOTTED AGAINST AGE OF OBSERVER (A POSITIVE SCORE IS IN FAVOUR OF WHITE LIGHT) EXPERIMENT A

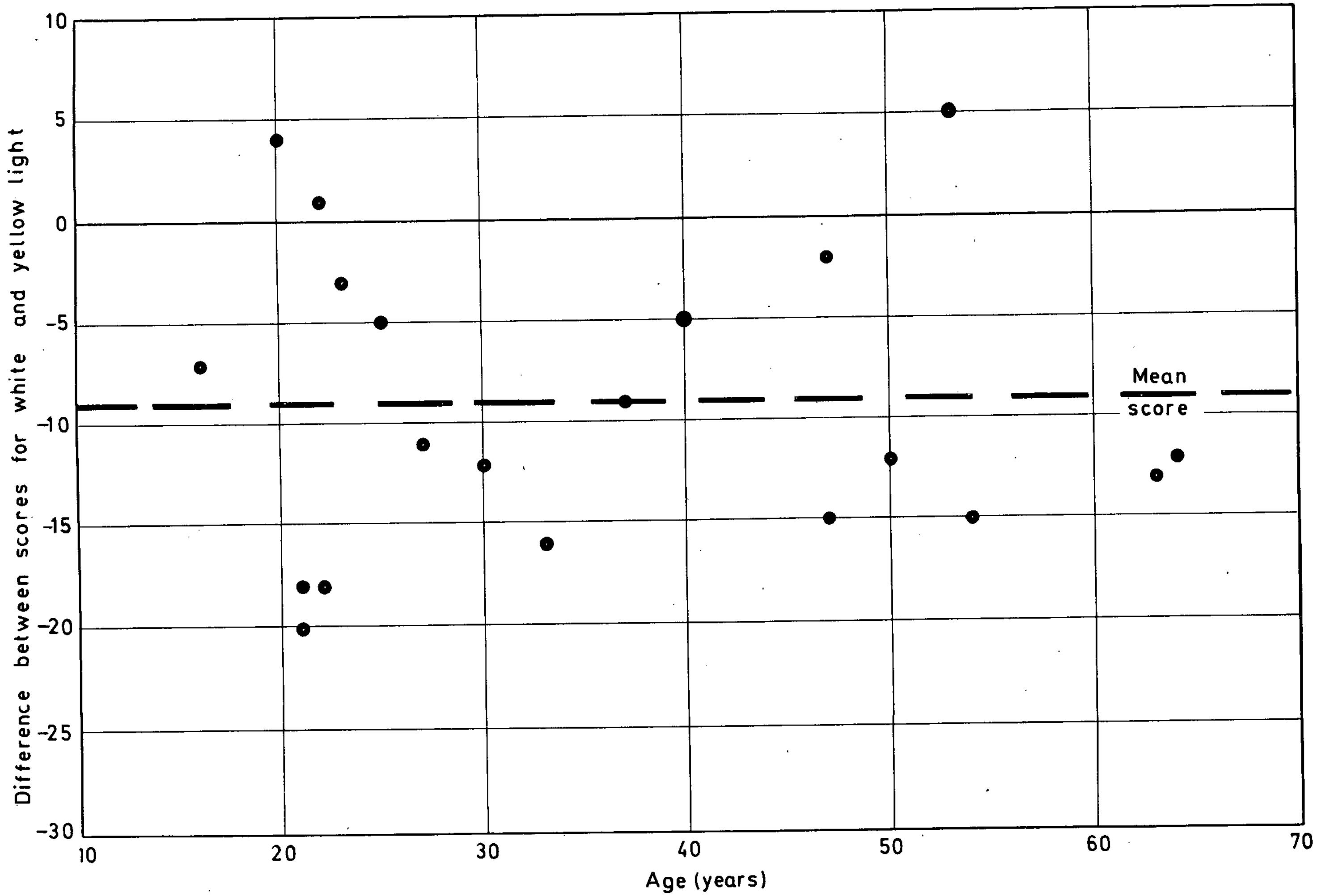


Fig. 5B. DIFFERENCE BETWEEN TOTAL SCORES FOR WHITE AND YELLOW LIGHT PLOTTED AGAINST AGE OF OBSERVER (A POSITIVE SCORE IS IN FAVOUR OF WHITE LIGHT) EXPERIMENT B

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